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Temperature conditions in the southern Gulf of St. Lawrence during 2008 relevant to snow crab

Conditions de température dans le sud du golfe du Saint-Laurent en 2008 relativement au crabe des neiges

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ABSTRACT

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) during 2008 were examined primarily from data collected during the snow crab and multi-species surveys. The snow crab survey was conducted in July-September while the multi-species survey was in September only. Data from the multi-species surveys, which are available for a much longer period than those from the snow crab survey, were compared to their normal conditions (1971-2000). Additional temperature data from other fisheries surveys and oceanographic studies in these same areas were also examined. In the Southern Gulf of St. Lawrence during 2008, conditions were variable but tended to have cooled throughout much of the region compared to the previous year. Near bottom temperatures over a large portion of the deeper parts of the Southern Gulf were below (colder) the long-term (1971-2000) average, while the shallower parts exhibited warmer conditions. The cooler coastal water is consistent with a significant increase in the Gulf wide snow crab habitat index (area of the bottom covered by water temperatures between –1 and 3 °C) relative to 2007 and it is around the long-term average. The mean temperature within the area of -1°C to 3°C is below normal and fell considerably compared to last year. This is a typical situation as the two time series are negatively correlated. The core temperaturewas the fourth lowest of the time series and comparable to the value observed in the 1990s cold period. This represents a continuous decline of the core temperature since 2006 when the highest value of the previous 23 years was observed. The crabs caught during the annual snow crab surveys were found in cooler waters in 2008 than in 2006 and 2007, which is believed to reflect in large part the higher availability of warmer temperatures during 2006 and 2007. Typically, the catch analysis shows that the adult snow crabs have a preference for cooler water, but it isn't the case for 2008 when the percentage of crab caught in the cooler portion of the habitat was lower than usual. This is the third year in a row that this phenomenon is observed. The new habitat index, based on preferred temperatures, considerably increased from 2007 for both the males and females. The index is now above the time series averages with a value of 0.54 for the males and 0.48 for the females.

RÉSUMÉ

Les températures près du fond dans la partie du sud du golfe du Saint-Laurent (Plateau madelinien) ont fait l'objet d'un examen en 2008 principalement à partir des données issues des relevés sur le crabe des neiges (réalisés en juillet et septembre) et des relevés plurispécifiques (réalisés uniquement en septembre). Les données tirées des relevés plurispécifiques, qui sont disponibles pour une période bien plus longue que les relevés sur les crabes des neiges, ont été comparées aux conditions normales (1971-2000). On a également procédé à l'examen des données sur la température issues d'autres relevés de pêche et d'études océanographiques réalisés dans les mêmes zones. En 2008, dans le sud du golfe du Saint-Laurent, les conditions étaient variables mais la température affichait une tendance au refroidissement dans la majeure partie de cette région comparativement à l'année précédente. Les températures près du fond d'une vaste part des zones plus profondes du sud du Golfe étaient inférieures (plus froides) que la moyenne normale à long terme (1971-2000), tandis que les parties moins profondes affichaient des conditions plus chaudes. Ce constat des eaux côtières plus froides va de pair avec une hausse importante de l'indice de la superficie de l'habitat du crabe des neiges (superficie où la température au fond se situe entre -1 et 3 °C) à l'échelle du Golfe en 2007, et la température se situe autour de la moyenne à long terme. La température moyenne de l'intervalle -1 °C à 3 °C se trouve sous la normale, et elle a chuté considérablement comparativement à l'an dernier; ce qui est typique étant donné que les deux séries chronologiques sont habituellement corrélées négativement. La température du noyau de la zone était la quatrième plus basse de la série chronologique et pouvait être comparée aux valeurs observées dans la période la plus froide des années 1990. Ces données représentent une diminution constante de la température du noyau depuis 2006, lorsqu'elle a atteint le niveau le plus élevé des 23 dernières années. Les crabes capturés lors du relevé annuel sur le crabe des neiges ont été trouvés dans des eaux plus froides en 2008 qu'en 2006 et qu'en 2007, ce qui pourrait refléter en grande partie, croit-on, la plus grande disponibilité d'eaux moins froides au cours de 2006 et de 2007. En règle générale, l'analyse des prises indique que les crabes des neiges adultes affichent une préférence pour l'eau plus froide, ce qui n'est pas le cas pour 2008 puisque le pourcentage de crabes capturés dans la portion plus froide de l'habitat était moins élevé que d'habitude. Ce phénomène est observé pour la troisième année consécutive. Le nouvel indice de la superficie de l'habitat, fondé sur les températures de préférence, a augmenté considérablement depuis 2007, tant pour les mâles que pour les femelles. L'indice se situe désormais au-dessus des moyennes des séries chronologiques avec des valeurs de 0,54 pour les mâles et de 0,48 pour les femelles.

INTRODUCTION

Snow crab (*Chionoecetes opilio*) is a cold-water stenothermic species typically inhabiting bottom depths of 20-310 m (Squire 1990). It can be found in water with temperatures as low as -1.5°C (Lovrich et al. 1995). An active and very lucrative fishery presently exists in the southern Gulf of St. Lawrence (sGSL) (Fig.1), on Sydney Bight and on the northeastern Scotian Shelf. Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken by the combined efforts of the Gulf and Maritimes regions of the Department of Fisheries and Oceans (DFO) and the snow crab fishing industry (some fishing areas). The purpose of this research document is to provide information on the sea temperature conditions during 2008 in the main snow crab fishing areas (12, 19, E and F) in the southern Gulf (Fig. 2) and to compare these temperatures to their long-term means. This includes areal indices of the ocean bottom covered by water temperatures between -1°C and 3°C. Monthly mean temperature profiles and time series of the monthly mean temperatures at specific depths within snow crab fishing areas provide further information on sea temperature trends. Finally, the catch of snow crab during the snow crab survey as a function of temperature for the 2008 season is presented and compared to other years when temperature and catch data were available. Also presented is a times series of a new habitat index based on the preferred temperature habitat of commercial male crabs. The research document begins with a description of the temperature data, and then provides details of the methods used to analyze the temperature fields and finally present the results.

DATA

Near-bottom temperatures during 2008 in the areas of snow crab fishing were available from two main surveys in the Gulf of St. Lawrence. A total of 355 stations were occupied during the snow crab survey conducted from July to September (Fig. 3). The annual multi-species survey (formerly, the groundfish survey) was carried out in September and 191 stations were occupied, while an oceanographic survey provided information at 32 stations in the Northumberland Strait (Fig. 4). The snow crab survey obtained near-bottom temperatures with a thermistor recorder attached to the trawl. Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during both the multi-species and snow crab surveys. Other temperature data from the snow crab areas in 2008 were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive, and were derived from additional fisheries surveys, research surveys and measurements from ships-of-opportunity. Pre-2008 data were taken from the hydrographic database maintained at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia. This database contains an edited version of the entire MEDS holdings for the region. The catch information, i.e. the number of crabs per tow, is kept in a database maintained at the Gulf Fisheries Centre (GFC) in Moncton, New Brunswick.

METHODS

The near-bottom temperatures from data collected during the September and snow crab surveys were interpolated onto a specified grid using an objective analysis procedure known as optimal estimation. This is a four-dimensional interpolation technique; i.e. three space dimensions, two horizontal and one vertical, and the time dimension. In this study, the surveys were treated as synoptic and no interpolation in time was carried out. The details of the procedure are found in Drinkwater and Pettipas (1996). The maximum profile depth on the CTD for each station was assumed to be at the bottom. Checks against bathymetric charts were

carried out to ensure no large errors occurred as a result of this assumption. The maximum depth in the grid for the slope of the Laurentian Channel Shelf was taken as 500 m. The temperature grid has a mesh size of 0.1° x 0.1° latitude-longitude. The bottom temperature data were slightly smoothed for the purpose of contouring, which tends to spread out the gridded values; thus, the true gradients could be stronger than those depicted in the plots.

Long-term monthly climatological means of the near-bottom temperatures were estimated at each grid point based upon optimal estimations using all available data for the years 1971-2000 in the historical temperature, salinity database at the Bedford Institute. The 1971-2000 climatological means are then subtracted from the values derived from the 2008 survey. The differences are called temperature anomalies. A negative anomaly indicates that the 2008 temperature was colder than the long-term mean and a positive anomaly indicates that it was warmer than the long-term mean. Also examined was the change in temperature since the previous year by subtracting the 2007 optimally estimated temperatures from the 2008 estimates. A negative value indicates that 2008 was cooler than 2007, a positive value that it was warmer.

The snow crab habitat index, defined by Drinkwater et al. (1998) as the area of the bottom covered by temperatures between -1°C and 3°C (favorable temperature range for the adults snow crabs), was calculated from the gridded temperature fields derived from the multi-species survey. The temperature at each grid point was assigned the area of bottom (0.1° by 0.1°) associated with that particular grid point. The areas with temperatures between -1°C and 3°C, inclusive, were then summed. The mean temperature within this area was also estimated. The 2008 indices were compared to those derived from earlier surveys but augmented by any additional temperature data available for the particular year and month in question. The time series of the indices began in 1971 for the southern Gulf.

In addition to the bottom temperatures and habitat indices, monthly mean temperature profiles for 2008 were determined within each of the snow crab areas (Fig. 2) from the BIO database. All available data within each of these areas were averaged by month at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250 and 300 m, where possible). An "annual" anomaly profile was determined for each year by averaging the available monthly anomalies, regardless of how many months were available. Time series of monthly mean temperatures at representative depths for each area are also provided. Long-period trends represented by five-year running averages of the "annual" anomalies are also shown.

The catch of snow crab as a function of temperature was also examined. The temperatures at which the crabs were caught were partitioned into 0.5°C bins and the depths into 20 m bins. The frequency distribution of the crab temperatures was expressed in percentages within each of the bins. These were then compared with the frequency distribution of the available temperatures at all of the stations sampled. Finally, comparisons were made between the 2008 results and those from 2007.

Based on the crab distribution and the work of Marcil et al. (2009), a new habitat index was definied and a time series starting in 1971 was provided. The preferred habitat index is a time-varying spatial variable describing the suitability of the environment (temperature) for snow crab and is based on the percentage proportion of individuals found at each temperature.

$$P_i = \frac{C_i}{C_i + A_i} \qquad (1)$$

Where P_i is the proportion of crab found at temperature interval i. The habitat index is represented by a function, based on the distribution of commercial crab within a range of temperature, that can describe a habitat as been very favourable (value 1) to unfavourable (value 0). A logistic function ($\phi(\theta_i)$) was fitted to the proportion (P) of crab found at each 0.1°C interval from -1.5°C to 10°C using the Microsoft Excel solver tool.

$$\phi(\theta_i) = \frac{1}{1 + \exp[a(\theta_i - \theta_{0.5})]} \qquad (2)$$

Where a is the function parameter defining the slope of the function, θ_i is the temperature at interval i, and $\theta_{0.5}$ is the temperature at the inflection point.

The equation parameters are a=0.367, $\theta_{0.5}$= 0.71 for the males and a=0.495, $\theta_{0.5}$= 0.601 for the females.The maximum value (function value for a temperature of -1.5°C, freezing point in the sGSL) was used to scale the function from 0 to 1 and to form the habitat index. Applying the scaling factors results in a habitat index of 0.72 representing the 50% proportion for commercial males and 0.68 for mature females. in terms of population dynamic based on this habitat index, i) a crab will tend to move up the habitat gradient if found in an unfavourable habitat and ii) a favourable habitat will tend to retain more crab than an unfavourable habitat.

An annual mean habitat index value was computed using the sum of all the September habitat index values over the southern Gulf divided by the surface area. This value was used to compare the sGSL habitat suitability for snow crab among year.

RESULTS AND DISCUSSION

Bottom Temperatures

Data acquired during the multi-species surveys in September 2008 showed that bottom temperatures ranged from <0°C to over 17°C in the southern Gulf of St. Lawrence (Fig. 5). Most of the bottom was covered by waters <3°C with the largest portion of the Magdalen Shallows (50-80 m) covered by waters <1°C. Bottom waters, with temperature <1°C can also be seen in Chaleur Bay. In contrast to 2005, 2006 and 2007, there was a large area showing sub-zero values over the Magdalen Shallows in 2008 similar to the cold period observed in the 1990s. Bottom temperatures tend to increase from the center of the Magdalen Shallows towards the shallower, nearshore regions and towards the deeper Laurentian Channel. This is because in the Gulf of St. Lawrence during summer, cold temperatures are found at intermediate depths (50-150 m), sandwiched between warm solar-heated upper layer waters and the relatively warm, salty deep waters in the Laurentian Channel. The latter originate from the slope water region off the continental shelf and are transported up the Channel. The cold waters are known as the cold intermediate layer (CIL). Although the deeper waters are warmer than the CIL, their density is greater because of higher salinities. In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is from atmospheric cooling of the water within the Gulf of St. Lawrence in winter with additional input through advection of cold Labrador Shelf water through the Strait of Belle Isle. The latter varies annually, but with a mean of approximately 35% of the total volume of the CIL (Petrie et al. 1988). As often observed in the past, the warmest near-bottom temperatures in the southern Gulf in 2008 were in Northumberland Strait where the analysis suggests they reached over 17°C (Fig. 5). Unusually,

bottom waters in St. Georges Bay were not as warm as during the previous years.

Temperature anomalies over a large portion of the deeper part of the Magdalen Shallows were below normal, while the shallower parts exhibit warmer than normal conditions (Fig. 6). The highest negative anomalies (as low as -4°C) are located along the northeast coast of Prince Edward Island (PEI) and around Magdalen Islands. There is also a cold spot in Chaleur Bay and offshore of Cape Breton. The highest positive anomalies (+3 to 4°C) appeared along the coast of New Brunswick, off northwestern PEI, East Northumberland Strait and along the slope of the Laurentian Channel. However, anomalies in shallow water areas must be viewed with caution since the largest uncertainties in the optimally estimated temperature fields are in the nearshore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lie close to the strong vertical gradient in temperature, called the thermocline. Indeed, in these regions the mixed layer may at times extend to the bottom in response to wind storms producing large variability in the near-bottom temperatures. Second, the optimal estimation routine extrapolates horizontal temperature gradients to the coast if there are no data inshore. This can lead to fictitious data, especially in regions of strong horizontal temperature gradients.

Relative to 2007, bottom temperatures during the 2008 multi-species survey were significantly cooler over most of the southern Gulf (Fig. 7). The Eastern Northumberland Strait, St. Georges Bay, the coastal water of Cape Breton and the south east of Magdalen Islands were significantly cooler than the previous years. Shediac Valley also exhibit much cooler bottom waters compare to 2007. The negative difference is over 4°C in St. Georges Bay and represents a continuous return to cooler conditions that were also observed in the 1990s. The head of Chaleur Bay showed bottom temperatures warmer in 2008 than in 2007, and similar observations can be made for the waters around Miscou Island.

The spatial pattern of the bottom temperatures from the snow crab survey in July-September 2008 is similar to the one obtained from the 2008 multi-species survey but not identical (Fig. 8). This is due to the large temporal spread of the snow crab survey (almost three months, July to September), while the multi-species survey data is all acquired in September. Usually there is a seasonal deepening and warming of the upper mixed layer, especially in the shallower regions. Other possible causes of the differences, besides seasonal warming in the shallow regions, may be differences in instrument accuracy (the CTD being more accurate than the thermistor recorder), a relative rapid point measurement (CTD) versus an average over a trawl distance (snow crab survey), and the difference in depth of the measurement (the thermistor is on bottom while the CTD will be a few to several meters above the bottom).

Snow Crab Habitat Index

From the September multi-species survey, a time series of the snow crab habitat index (area of bottom covered with waters between -1°C and 3°C) based upon optimally estimated bottom temperatures is available from 1971 to 2008. The southern Gulf grid contains a total area of 70,039 km^2 (847 grid points). The authors also estimated the average temperature within the area covered by temperatures in the range -1°C to 3°C and correlated these with the habitat index.

In 2008, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the multi-species survey increased compared to 2007. It was 51,698 km^2 and was very close to the long-term mean (1971-2000) of approximately 51,969 km^2 (Fig. 9). The 2008 value represents 74% of the total Shallows area, and was 6% bigger than in 2007, 2% larger than in 2006, but almost 3% smaller than in 2005. In terms of area, this represents a return to

normal conditions compared to 2007; the snow crab habitat index in 2007 was the third lowest value over the 35-year record, with 1984 and 1992 being the highest values. The lowest values were reached in 1980 and 1981, while 2002 showed the fourth lowest value. Note, however, that the variability in the habitat index for the Shallows tends to be small. The index only varied between 65% and 84% of the total area available over all years.

The mean temperature within the habitat area in 2008 (0.30°C) decreased significantly compared to 2007 (by 0.55°C). The value is significantly lower than the long-term mean and represents the lowest value since 1995 when the minimum (0.15°C) of the time series was reached and is the fourth lowest value of the time series, with 1984 and 1993 also having lower temperatures. The 2008 value is sharply contrasting with the ones observed during the 1999-2002 and 2005-2007 warm periods. The index was also below the long-term during September 2003 and 2004. For recent years, the 2006 mean temperature, within the habitat, was the highest of the previous 24 years. Other high values where reached in 1971, 1977, 1981 and 1982 (maximum at 1.31°C). Year 2008 is a usual year in the sense that the temperature decreased while the habitat index was increasing, i.e. that normally the two time series are negatively correlated. This brings the correlation between the habitat index and the mean temperature over the years 1971-2008 to a value of -0.46, and this is not statistically significant.

Monthly Mean Temperature Anomaly Profiles and Time Series

The monthly mean temperature anomaly profiles were determined for each of the snow crab fishing areas for the southern Gulf (see Fig. 2 for the area boundaries used in the temperature analysis). The monthly mean temperatures at standard depths were estimated by averaging all of the available data within the area regardless of when in the month it was measured. Similarly, no adjustments were made for the spatial distribution of data or the amount of data that contributed to the average. In some cases the "average" was based upon only a few measurements while in other months it was based on over 200 stations. The long-term (1971-2000) mean was then subtracted to obtain a temperature anomaly. In addition to the profiles, temperature time series at depths considered representative of the near-bottom region within each of the fishing areas are presented. Because of the limited amount of data within the areas over which the averages were made and the possibility of spatial variability in temperature within the areas, any one point or profile may not be truly representative of "average" conditions for the month. Interpretation of any anomalies therefore must be viewed with caution. While no significance should be placed on any individual monthly anomaly, persistent features are considered real.

Data for 2008 over the central Magdalen Shallows (Area 12 in Fig. 2) were available for March to December covering 10 months, which is more than usual (Fig. 10). The annual mean shows warmer than normal condition down to around 50 m, with an anomaly reaching over 2°C at the surface. Between 50 and 140 m, the conditions were cooler that normal reflecting that the CIL layer was cooler that usual. Below 150 m, which is primarily limited to the Laurentian Channel and the deep trough off Cape Breton (Area 19), monthly temperature anomaly profiles were slightly positive, except for August, and the annual anomaly was above zero. The time series of monthly mean temperatures at 75 m in Area 12 also shows high month-to-month variability with a definite tendency for below normal temperatures over most of the period since the mid-1980s to 1999 and warmer than normal temperatures between 2005 and the end of 2007 and cooler conditions since that time (Fig. 11). Part of the high month-to-month variability is believed to be due to differences in the extent of the spatial sampling but the long-term pattern matches that observed elsewhere and is considered real.

Temperatures within Area 19 along the Gulf side of Cape Breton Island were also used in this analysis. They include deep data (>150 m) from the Cape Breton Trough. Measurements were available for March and June to November in 2008 (Fig. 12). Except for August, the conditions were warmer than normal down to 50 m for most months with colder-than-normal water at depths. As for 2007, the surface of the ocean was significantly warmer in November with an anomaly of over 4°C. The monthly anomalies are then reflected on the annual average with warmer than normal conditions down to around 50 m and cooler than normal in the deeper portion of the fishing area until 200 m where warmer-than-normal waters were present. However, these averages are based on few data and should be interpreted cautiously. The time series at 100 m clearly shows that above normal temperatures observed during 2007 were followed by below normal values in 2008 (Fig. 13). The last value of the five-year running mean at this depth is still close to zero, meaning that the average temperature for 2003-2008 was close to the 1971-2000 average temperature.

Data for June, July and September were available from Area F in 2008 (Fig. 14). No temperatures were recorded in the deeper part of this area (up to 300 m). The surface water was warmer than normal, especially in July, with an anomaly of 5°C. The water column was cooler than normal down from 35 during the three sampled months with warmer-than-normal conditions at depth greater than 150 m in September. These conditions are also reflected in the annual mean profile (Fig. 14). The time series at 100 m in Area F is similar to the one for Area 19 (Fig. 15), i.e. a strong tendency towards below normal anomalies from the mid-1980s to the late 1990s, a general warming starting around 1992 and a levelling off at the end of the 1990s and a slight cooling at the end of the time series. Warmer-than-normal temperatures were observed from 1999 to 2002, but they have been closer to normal since then which is seen in the last value of the five-year running mean although year 2008 was clearly colder than normal at that depth. For most years, the data at 100 m are reasonably representative of conditions from 75 to 150 m in Area F.

To the north in Area E, data were available for 6 months: March, June, July, August, September and November (Fig. 16). As for the other areas, monthly mean temperatures were above normal in the surface layer during most sampled months. The largest cold anomaly of -3°C was observed at around 25 m in September. There were strong positive anomalies at the surface, especially in July when the anomaly reached 8°C. The annual average exhibited cooler than normal conditions between 35 and 150 m and warmer than normal conditions down below. The temperature time series at 100 m for Area E shows the typical pattern of negative anomalies since the mid-1980s and a general upswing beginning in the mid-1990s (Fig. 17). The cooler than normal temperatures at this depth in 2008 contrast with the warmer than normal values observed in 2006 and 2007, but they were similar to the below normal values present in 2004.

The general trends in the temperature anomalies in the near-bottom waters throughout the Magdalen Shallows are similar. This is highlighted in Fig. 18 that shows the five-year running means of the temperature anomalies for Areas 12, 19, E and F. These show the continuously decreasing temperature from the last maximums in the early 1980s to the minimums in the early 1990s and then the general warming trend up to the early 2000s and a slight decrease at end of the time series, in recent years.

Snow Crab Catches by Temperature

The catches (from the trawl survey) of snow crab as a function of temperature during the 2008 snow crab survey in the Gulf are shown in Fig. 19. Over 96% of the crabs were caught in temperatures below 3°C, which is higher than in 2007 (95%) and 2006 (92%). Typically, there is a tendency for the snow crabs to be captured in the cooler portion of the favourable habitat

(which is defined as waters with a temperature range of -1°C to 3°C), but this is not as obvious in 2008 as in 2003 and 2004 when cooler conditions were also observed. The distribution of the catches is slightly lower than the distribution of the bottom temperatures for the bins lower than 0.5°C. However, the snow crabs in 2008 were generally caught in cooler waters than in 2007 and 2006, a situation that reflects the progressive ambient temperatures changes. The cumulative percentages of snow crab catches and bottom temperatures (Fig. 20) are unusual as the snow crabs curve is usually ahead of the temperature curve, i.e. that they do not cross as seen in 2008. Since there has been a gradual cooling of the bottom temperatures since 2005, this suggests that the snow crab population needs some time to adjust its distribution to new habitat state. These changes in the portion of the very cold water observed at the bottom over the Magdalen Shallows might be triggering movement of the snow crab population.

The Snow Crab Preferred Habitat Index (PHI)

The 2008 PHI spatial patterns, based on the method of Marcil et al. (2009), are shown in Fig. 21 for both the commercial males and mature females. A preferred habitat (index >0.72) for commercial males is seen over most of the Magdalen Shallows. A high habitat index is present over Bradelle Bank and over smaller area between the northeast tip of PEI and Magdalen Islands. For the mature females, the habitat index corresponding to the 50% proportion is 0.68, and maximum values are also observed in the same areas as the commercial males.

The Mean Preferred Habitat Index (MPHI) in the southern Gulf, based on available September temperatures, can be used as an indicator of the habitat suitability for adult snow crab (Fig. 22). The MPHI is a relative index and depends on the grid size used to do the calculation. However, it gives an estimation of the relative changes over the years. The habitat suitability for mature females is lower than for commercial males for all years because of females' preference for colder temperatures. In 2008, the habitat index for both the males and females considerably increased from 2007. The index is now above the time series averages with a value of 0.54 for the males and 0.48 for the females. Since 1999, there had been an increase in bottom temperature in the southern Gulf which had the effect of decreasing the habitat suitability for adult snow crab, but this tendency was reversed in 2008. The minimum habitat indexes were reached in year 2002 for both the commercial males and mature females although very low values were also observed from 2005 to 2007.

SUMMARY

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) and in the northeastern Scotian Shelf during 2008 were examined primarily from data collected during the snow crab and multi-species surveys. The snow crab survey was conducted in July-September, while the multi-species survey was in September only. Data from the multi-species surveys, which are available for a much longer period than those from the snow crab survey, were compared to their normal conditions (1971-2000). Additional temperature data from other fisheries surveys and oceanographic studies in these same areas were also examined. In the southern Gulf of St. Lawrence during 2008, conditions were variable, but tended to have cooled throughout much of the region compared to the previous year. Near bottom temperatures over a large portion of the deeper parts of the southern Gulf were below (colder) the long-term (1971-2000) average, while the shallower parts exhibit warmer than normal conditions.

The cooler coastal water is consistent with a significant increase in the Gulf wide snow crab habitat index (area of the bottom covered by water temperatures between –1°C and 3°C) relative to 2007, and it is around the long-term average. The temperatures within the area of

-1°C to 3°C was below normal and fell considerably compared to last year. This is a typical situation as the two time series are negatively correlated. The core temperature is the fourth lowest of the time series and is comparable to the value observed in the 1990s cold period. This is continuous decline of the core temperature since 2006, when the highest value of the previ us 23 years was observed.

The crabs caught during the annual snow crab surveys were found in cooler waters in 2008 than in 2006 and 2007, which is believed to reflect in large part the availability of warmer temperatures during 2006 and 2007. Typically, the catch analysis show that the adult snow crabs have a preference for cooler water, but it is not the case for year 2008, when the percentage of crab caught in the cooler portion of the habitat is smaller than usual. This is the third year in a row that this phenomenon is observed. The new habitat index, based on preferred temperatures, considerably increased from 2007 for both the males and females. The index is now above the time series averages, with a value of 0.54 for the males and 0.48 for the females.

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FIGURES

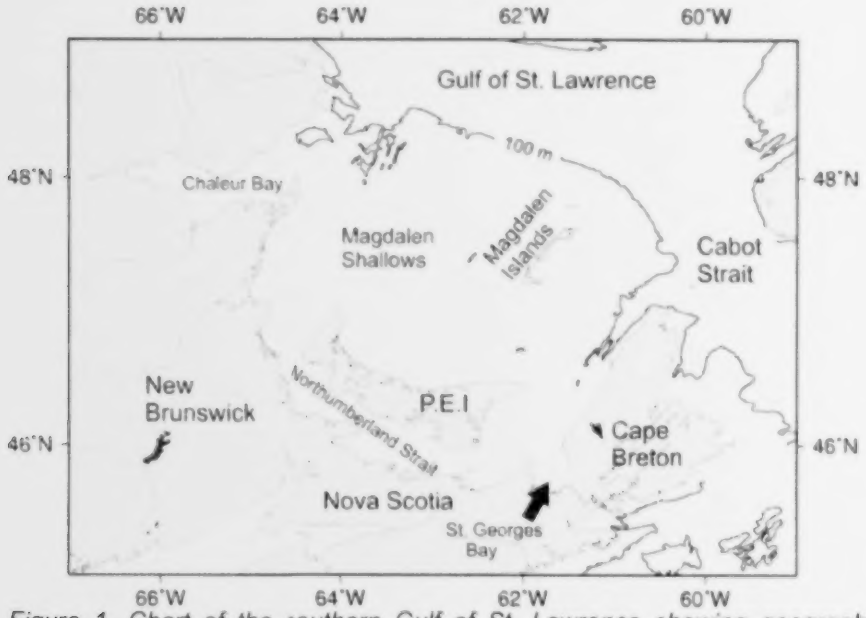

Figure 1. Chart of the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

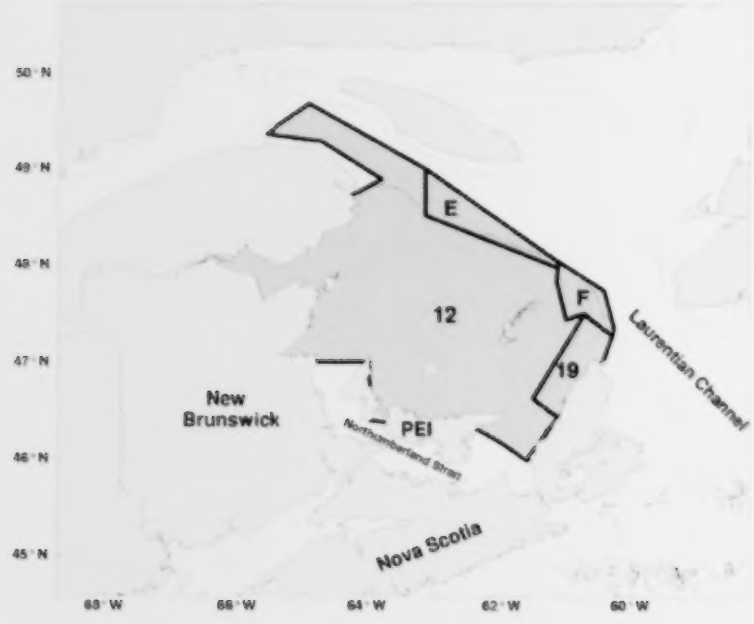

Figure 2. The southern Gulf of St. Lawrence showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated.

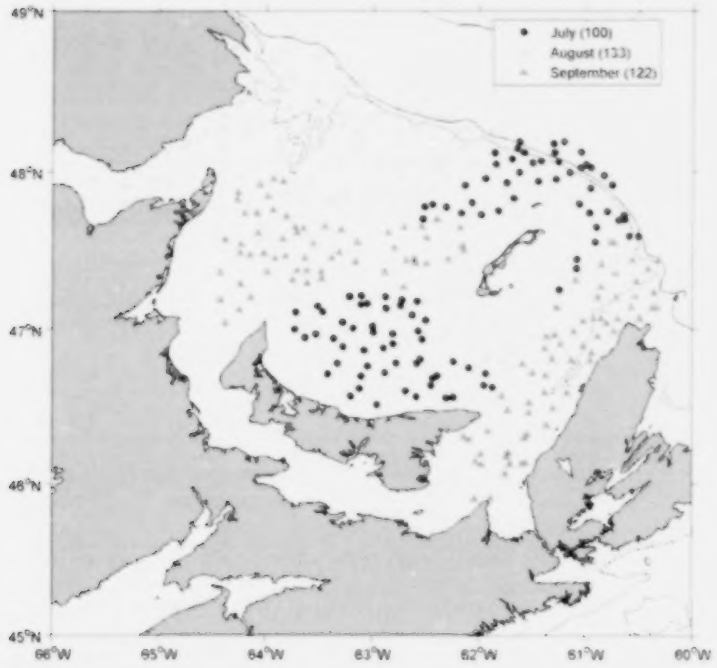

Figure 3. The location of the bottom temperature stations during the July-September 2008 snow crab survey.

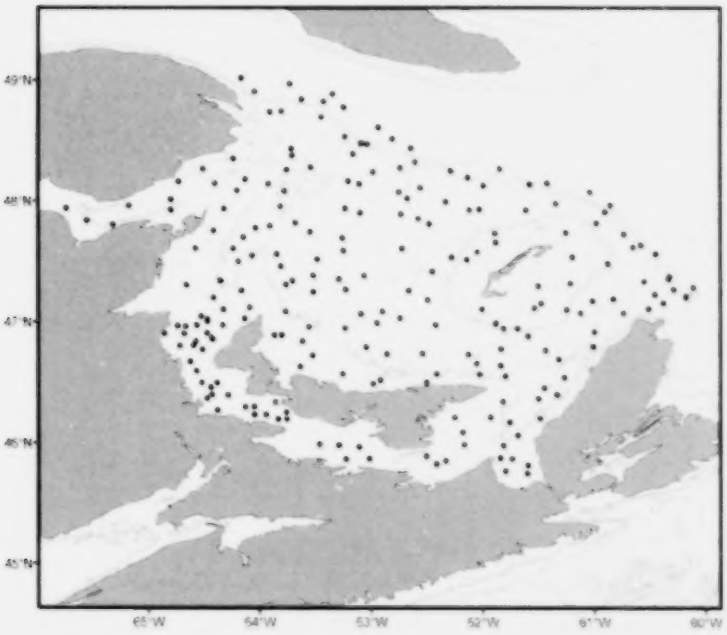

Figure 4. The location of the CTD stations during the September 2008 multi-species survey (Teleost) and Northumberland Strait Survey (Royal Sea).

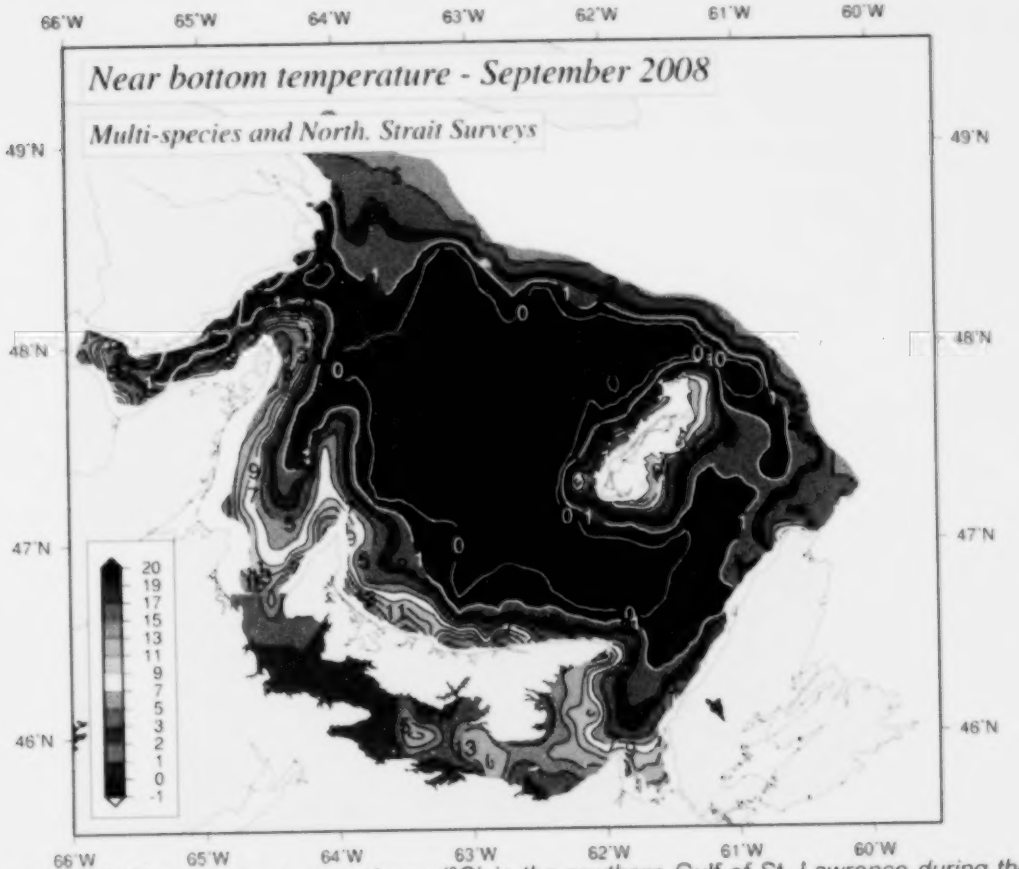

Figure 5. Near-bottom temperatures (°C) in the southern Gulf of St. Lawrence during the 2008 September multi-species survey.

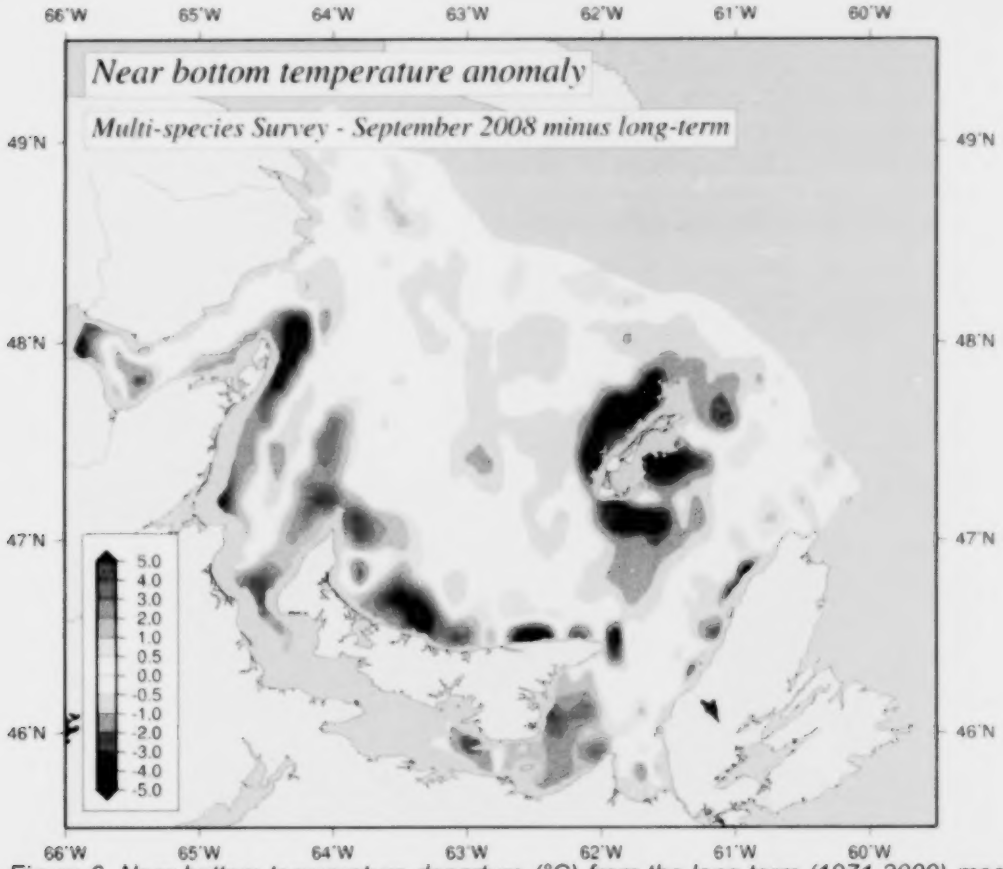

Figure 6. Near-bottom temperature departure (°C) from the long-term (1971-2000) mean in the southern Gulf of St. Lawrence during the 2008 September multi-species survey. Blue areas represent colder-than-normal temperatures while red regions represent warmer-than-normal conditions.

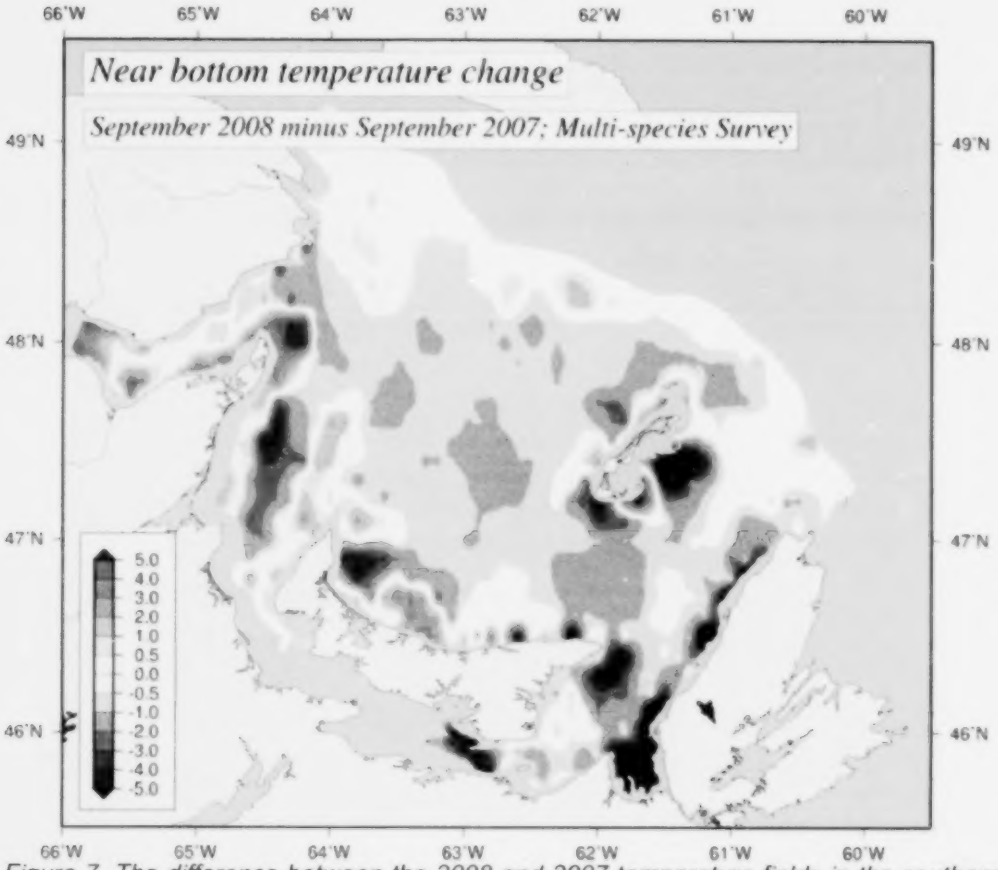

Figure 7. The difference between the 2008 and 2007 temperature fields in the southern Gulf of St. Lawrence for the September multi-species survey. Positive values (red) indicate temperatures in 2008 had warmed and negative values (blue) that they had cooled compared to 2007.

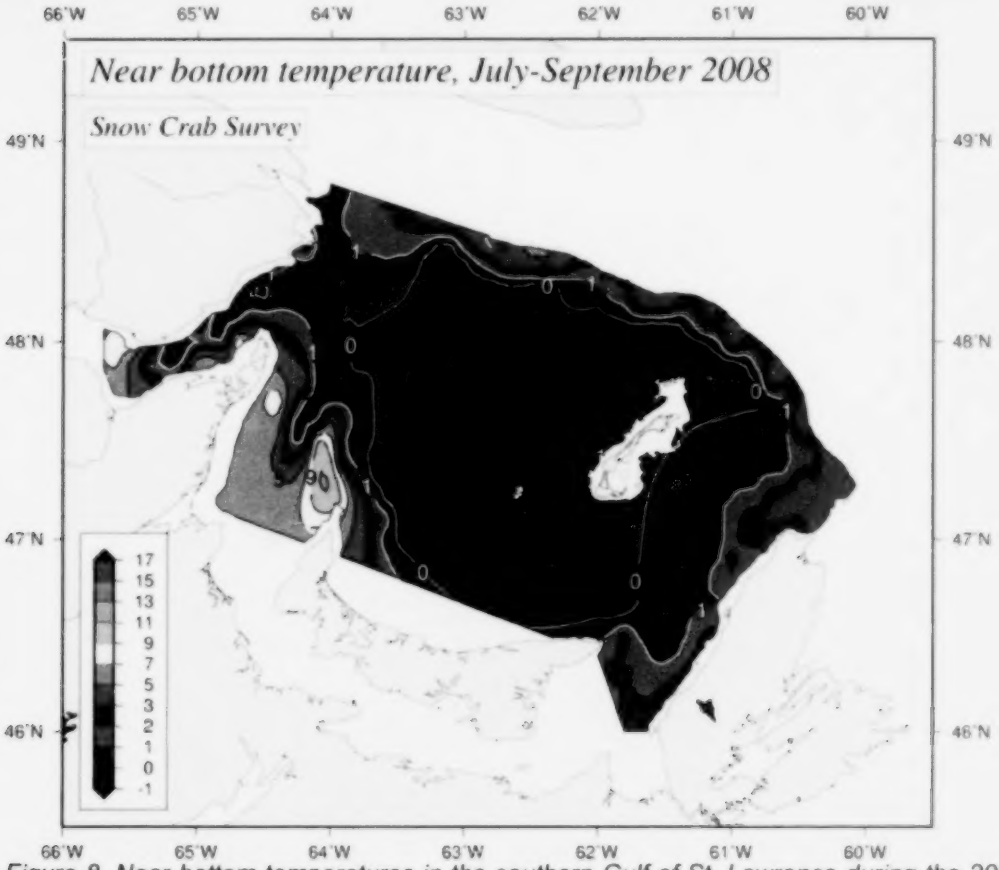

Figure 8. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2008 July-September snow crab survey.

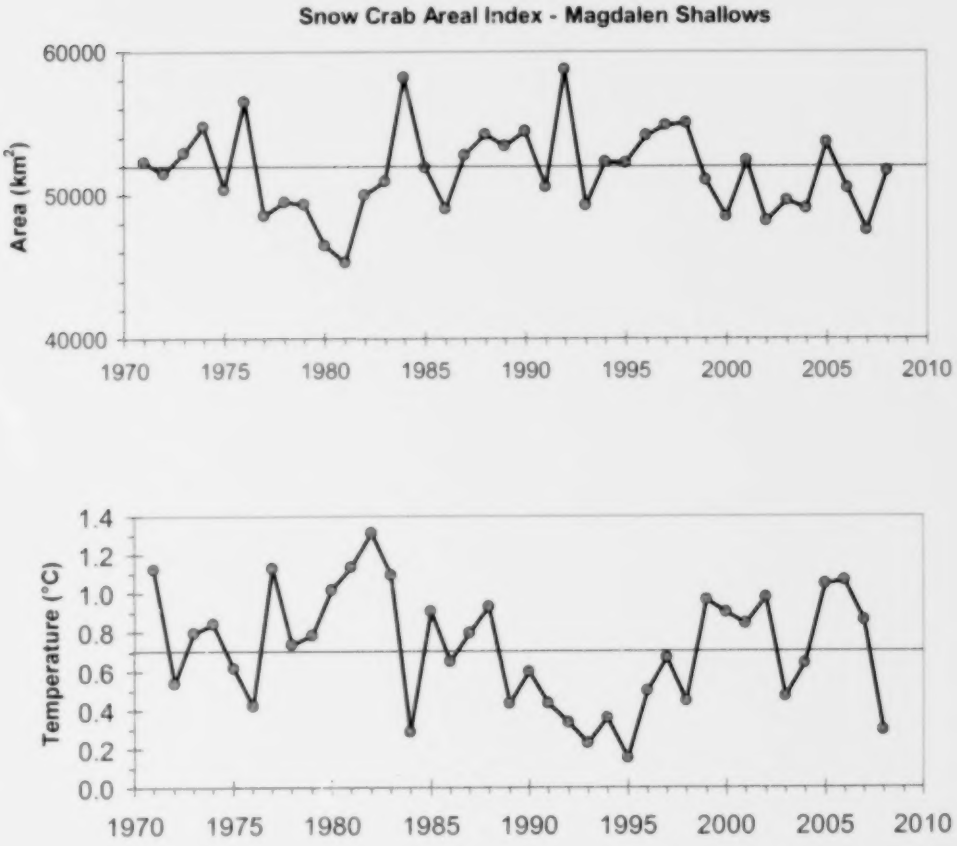

Figure 9. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel).

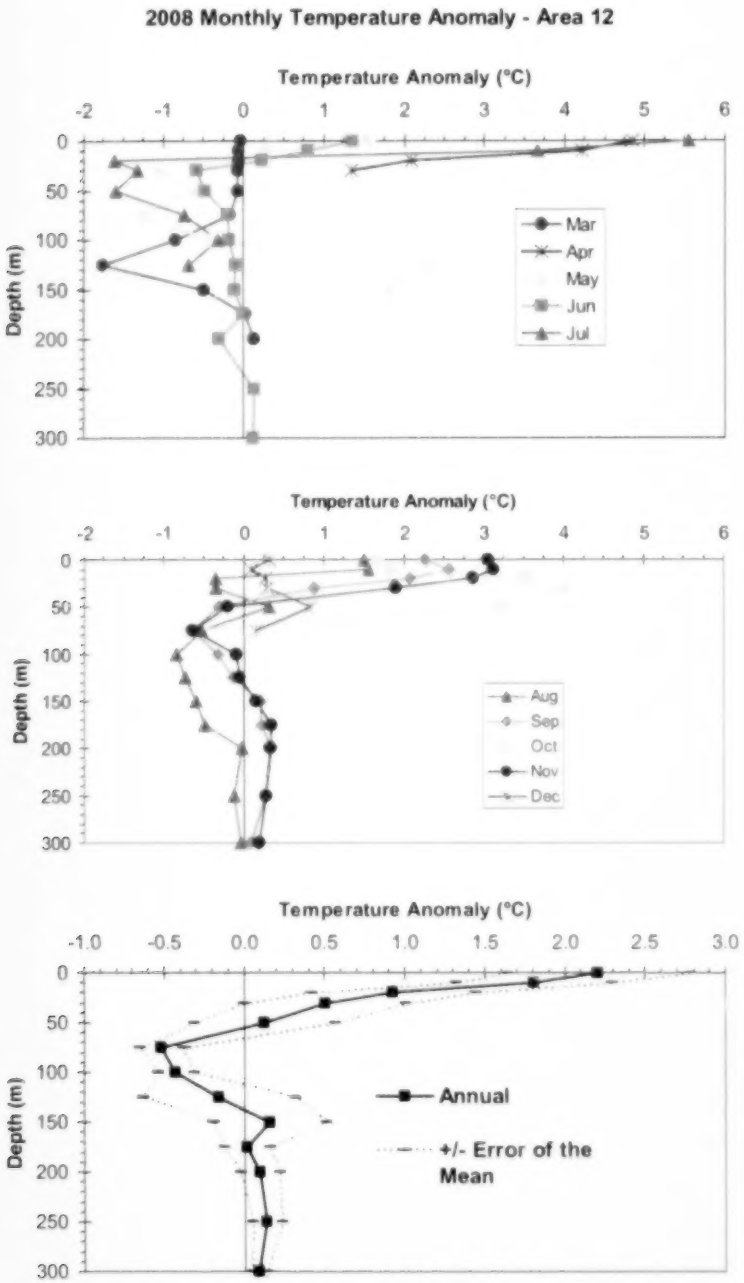

Figure 10. Monthly (top two panels) mean temperature anomalies and annual temperature anomalies ± error of the mean (bottom panel) during 2008 for snow crab fishing Area 12.

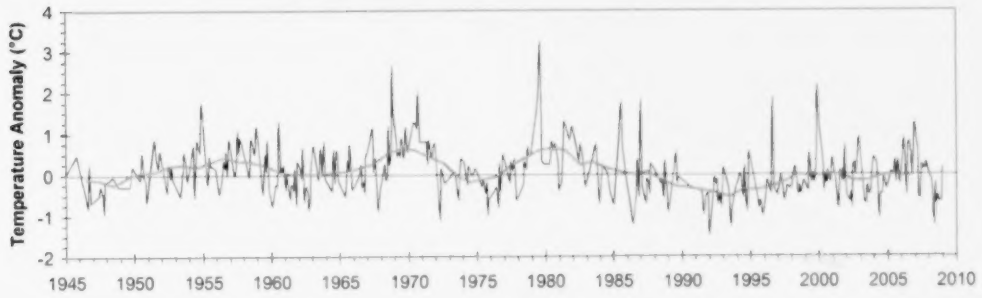

Figure 11. The time series of the monthly (black line) and the five-year running mean of the annual temperature anomalies (red line) at 75 m for snow crab fishing Area 12.

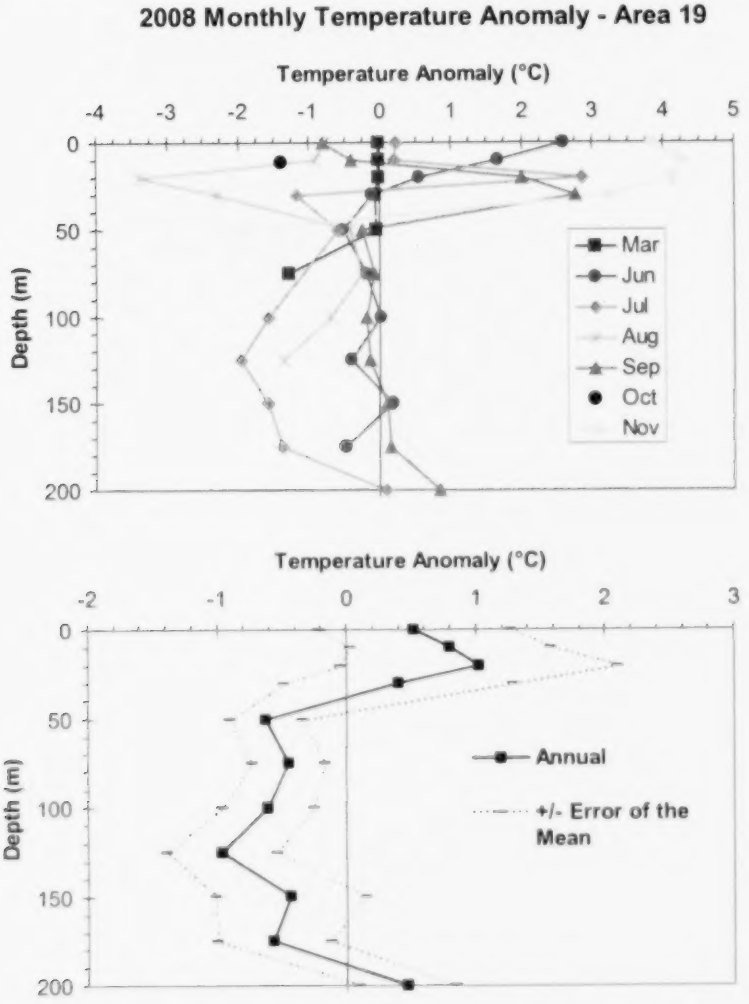

Figure 12. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2008 for snow crab fishing Area 19.

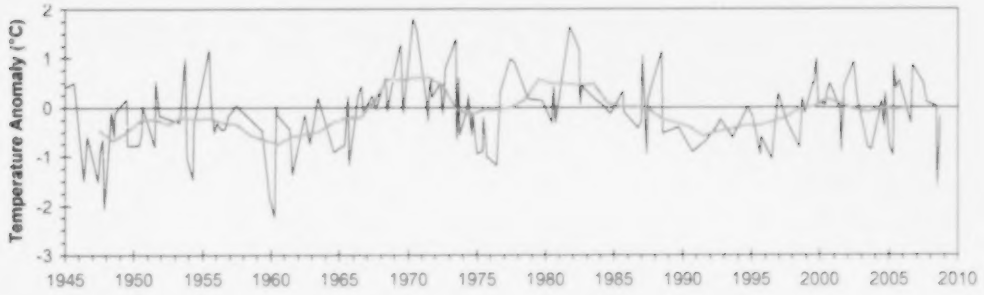

Figure 13. The time series of the monthly (black line) and the five-year running means (red line) of the annual anomalies at 100 m for snow crab fishing Area 19.

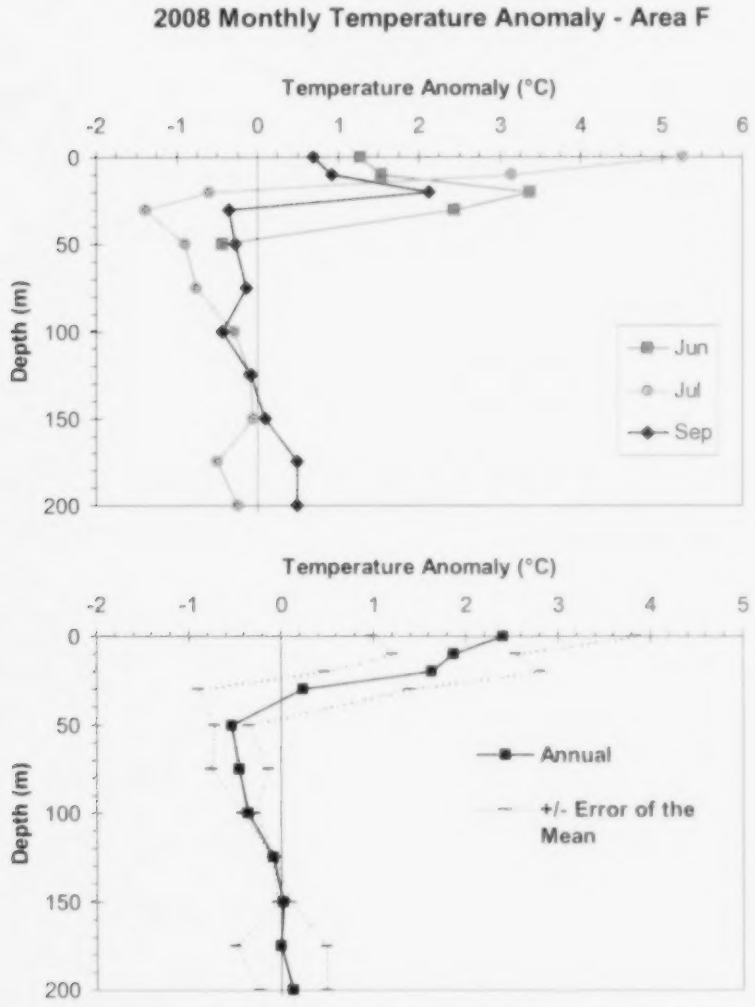

Figure 14. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2008 for snow crab fishing Area F.

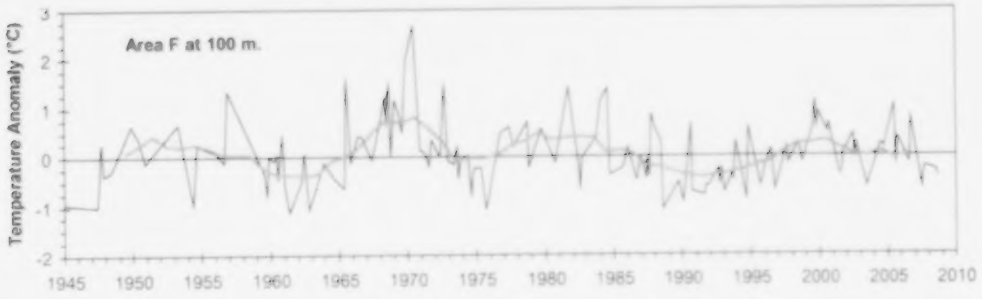

Figure 15. The time series of the monthly (dashed line) and the five-year running means (solid line) of the annual temperature anomalies at 100 m for snow crab fishing Area F.

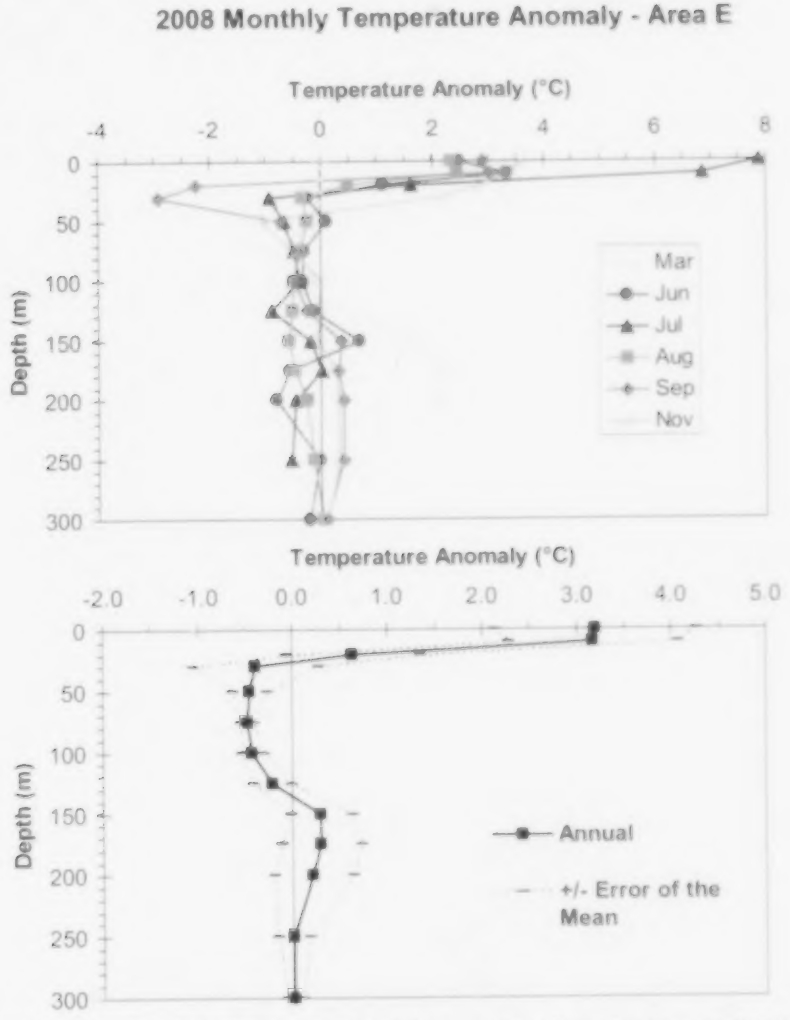

Figure 16. Monthly mean temperature anomalies (upper and mid panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2008 for snow crab fishing Area E.

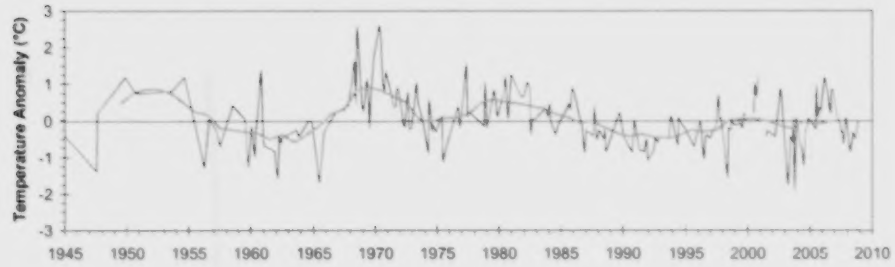

Figure 17. The time series of the monthly (dashed line) and the five-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area E.

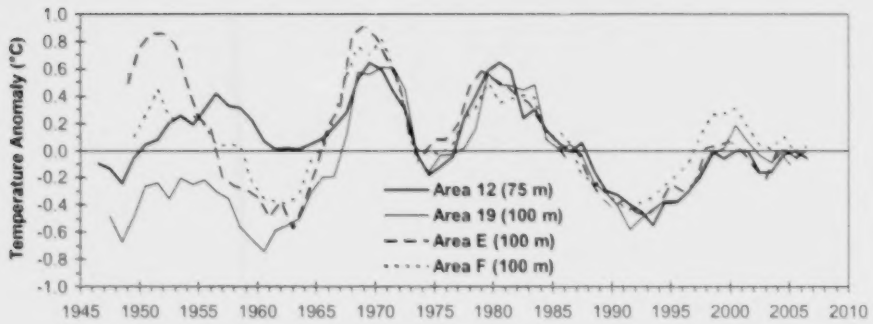

Figure 18. The five-year running means of the near bottom temperature anomalies for Areas 12, 19, E and F.

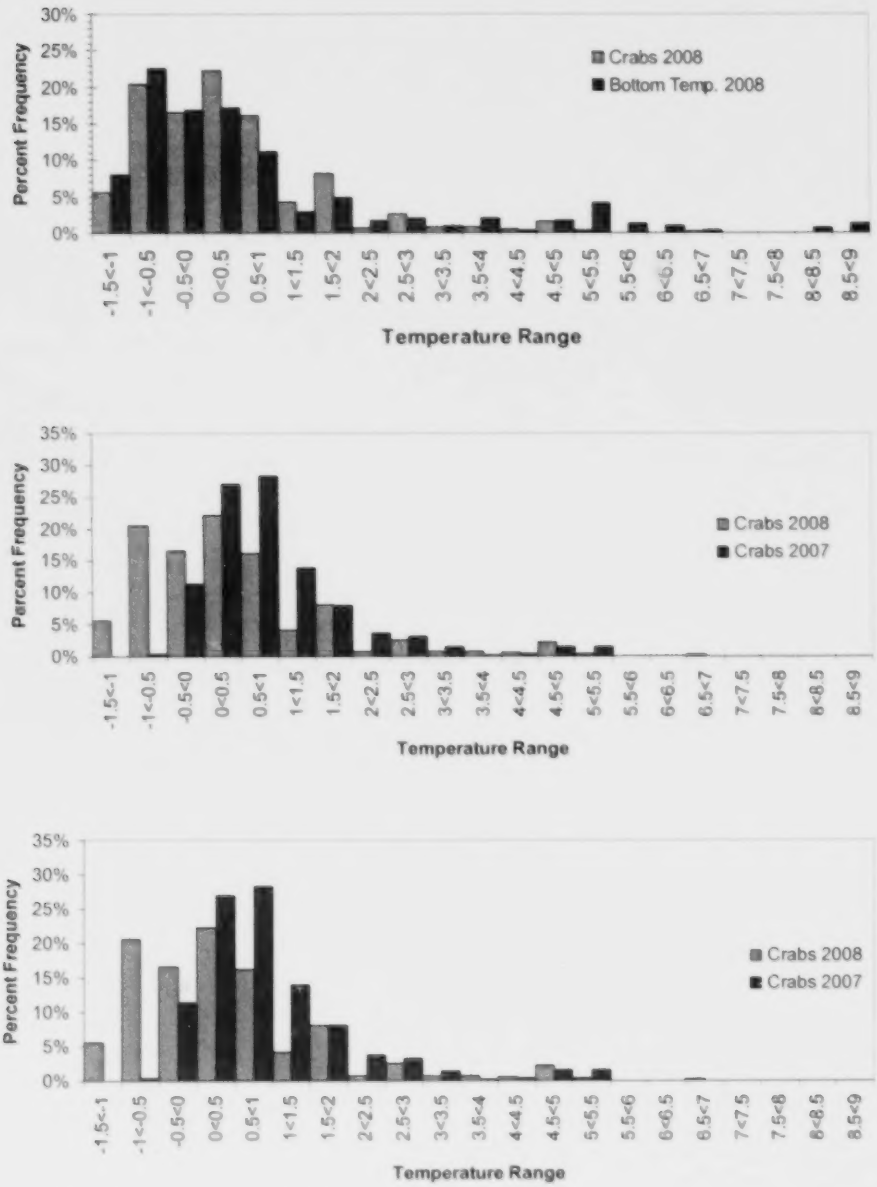

Figure 19. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations during the 2008 Gulf of St. Lawrence snow crab survey (top panel). The frequency distribution as a function of temperature for the stations occupied (middle panel) and for the snow crab catches (bottom panel) from the 2007 and 2008 Gulf of St. Lawrence snow crab surveys.

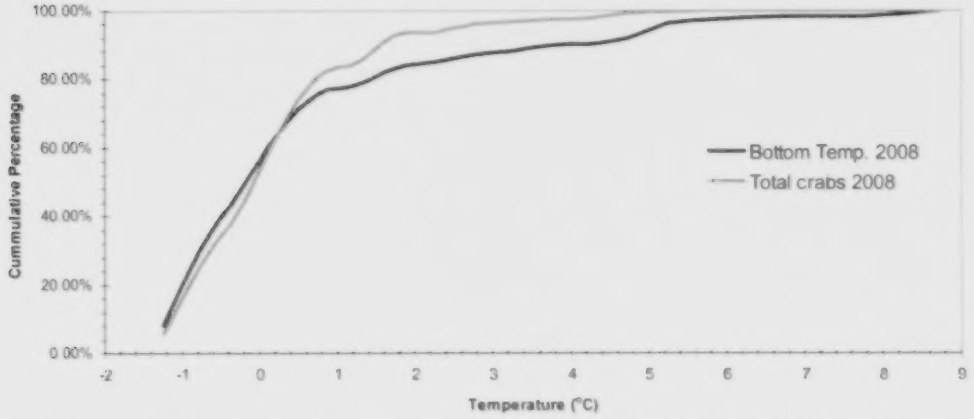

Figure 20. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations occupied during the snow crab survey in 2008.

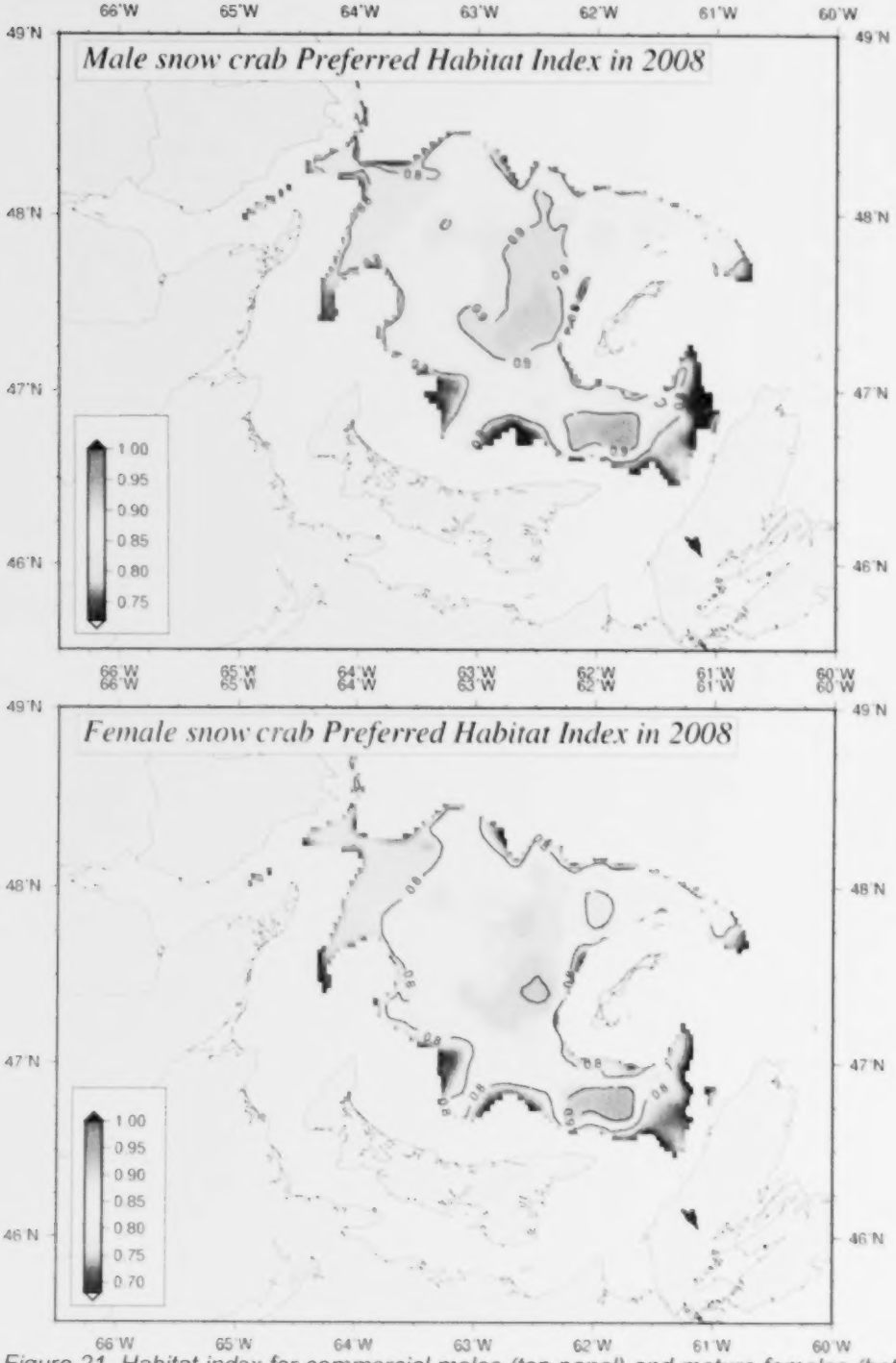

Figure 21. Habitat index for commercial males (top panel) and mature females (bottom panel) in 2008.

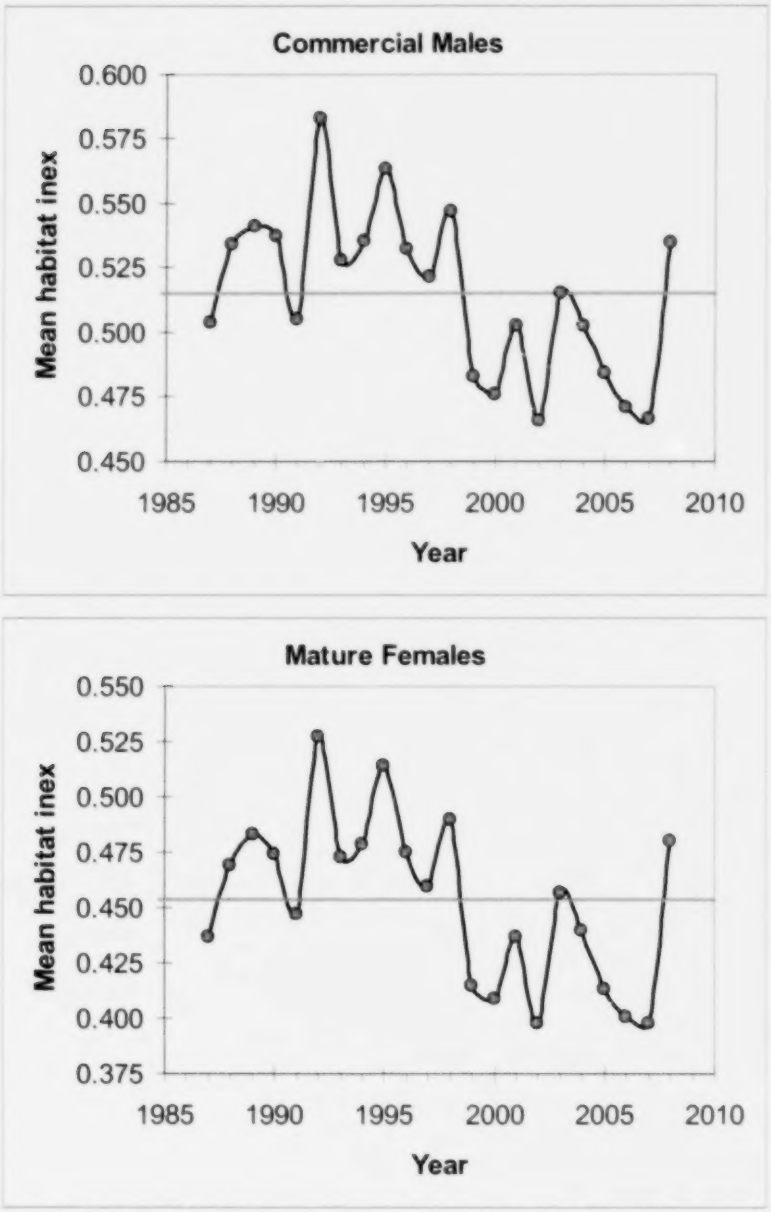

Figure 22. Mean habitat index for commercial males (top panel) and mature females (bottom panel) from 1987 to 2008.